AN EXPERIMENTAL STUDY FOR IMPROVING THE DURABILITY OF CONCRETE BRIDGE DECKS

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ABSTRACT

The premature deterioration of concrete bridge deck is often observed on the expressway in South Korea because they are directly exposed to traffic loads and severe environmental conditions. The main cause of deterioration of decks with asphalt overlay is the freeze-thawing action in the area where the concrete is saturated by water and de-icing salt.

To develop more durable concrete deck, performance characteristic tests of high performance concrete (HPC) mixtures were carried out. In this study, 3 concrete mixtures with or without mineral admixtures were tested. The design compressive strength was 30MPa. HPC (that the binder was composed of the 60% of cement, 30% of ground granulated blast furnace slag, and 10% of fly ash by weight ratio) was turned out to have the good durability with crack resistance.

The 30MPa HPC developed with the ternary based cement by OEM was experimentally applied at a bridge deck on Honam expressway. According to the follow-up survey, there was no crack on the deck. The performance characteristics of HPC at the experimental construction field were better than equal to those of HPC in laboratory.

1. **INTRODUCTION**

Bridge decks are directly exposed to several environmental factors (freeze-thawing action, rain water, de-icing salt, and etc.). This results in the concrete bridge deck being more vulnerable to deterioration and damage than other component members of bridge. Actually they frequently experience the spalling caused by the corrosion of rebars due to de-icing salt and the scaling caused by the freeze-thawing action on a deck surface.[1)] Therefore, the durability improvement of bridge concrete decks is the most effective measure for extending a service life of bridge. To develop the high performance concrete available in those severe conditions, 3 concrete mixtures with or without mineral admixtures were selected and tested on performance characteristics, concrete durability, and crack-resistance of fresh concrete as well as hardened concrete.

2. **MATERIALS AND MIXING**

2.1 **Materials**

2.1.1 **Cement and Mineral Admixtures**

The cement used in the test was ordinary Portland cement(OPC) and mineral admixtures were fly ash(FA), silica fume(SF) and ground granulated blast furnace slag(BS). All cement and mineral admixtures used in this study met the Korean Standards. Table 1 shows the chemical compositions and physical properties of the cementious materials.

Table 1 Chemical compositions and physical properties of the cementious materials

Items / Types	Chemical Compositions (%)							Physical Properties	
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Ig. loss	Density (g/cm^3)	Blaine (cm^2/g)
OPC	19.88	4.87	3.11	61.56	2.95	2.82	2.93	3.15	3,359
FA	52.30	25.50	6.10	3.40	0.90	-	4.30	2.19	3,714
SF	93.20	0.33	0.53	0.10	0.35	-	-	2.20	190,000
BS	31.88	12.64	0.39	42.46	6.38	3.63	0.65	2.91	4,339

2.1.2 **Aggregate**

Washed out sea sand with a density of 2.6 and fineness modulus of 2.76 was used as fine aggregate. Maximum size of coarse aggregate was 25mm. Table 2 shows the physical properties of each aggregate.

Table 2 Physical properties of each aggregate

Items / Types	G_{max} (mm)	Density (g/cm^3)	Absorption (%)	Fineness Modulus
Fine Aggregate	-	2.59	1.11	3.02
Coarse Aggregate	25	2.67	0.80	7.15

2.1.3 **Chemical Admixtures**

In this test, a polycarbonic acid type super-plasticizer was used. Table 3 shows the characteristics of the admixture used. Other AE agent was additionally used to adjust the air content in 6.5±1.0%.

Table 3 Properties of chemical admixture

Agent	Main Component	Color	Density (g/cm^3)	Note
Super-plasticizer	Polycarboxylic	Light yellow	1.13	Solidity:21.8%

2.1.4 **Concrete Mix proportions**

Concrete mix proportions were based on the concrete design specification applied to bridge decks in South Korean expressway. The design compressive strength was 30MPa that was higher than the present design strength of 27MPa. Table 4 shows the designed concrete mix proportions.

In order to identify an appropriate replacement ratio for each admixture in HPC bridge deck, the previous researches and literatures were investigated. It was found that the best replacement rate of each admixture has been determined within a certain range.[2-4] Durability performance of concrete was largely affected by using admixtures than the compressive strength. When the ground granulated blast furnace slag was used as an admixture, it was significantly contributed on the improvement of the chloride ion penetration resistance and scaling resistance. But the crack resistance of the mixture was inferior to the mixture used only OPC as a binder. Also, although the use of fly ash was found to increase crack resistance, it did not have a significant influence on chloride ion penetration resistance and scaling resistance.[5] Therefore the high performance concrete with both of ground granulated blast furnace slag and fly ash could be suggested as a solution for improving both crack resistance and durability.

The final concrete mixing proportions - 3 concrete mixtures - were set as shown in Table 5. OPC used only cement as binder. The binder of HPC was composed of 60% cement, 30% ground granulated blast furnace slag, and 10% fly ash by weight ratio. The other binder of HPC(NY) was composed of the 74% of cement, 20% of fly ash, and 6% of micro silica fume by weight ratio. Table 6 shows the test items of these mixtures.

Table 4 Conditions of concrete mixture

Design Strength(MPa)	$G_{max.}$(mm)	W/B	Slump(cm)	Air Content(%)	Agent
30	25	Blow 0.4	13±2.5	6.5±1.0	Super-plasticizer

Table 5 Mixing proportions

Classification	W/B	S/A	Water (kg)	Unit Content of Binder Material (kg/m^3)				Fine Agg. (kg)	Coarse Agg. (kg)	Super-plasticizer (kg)
				OPC	FA	BS	SF			
OPC	0.400	0.426	158	395	-	-	-	746	1037	2.37
HPC	0.384	0.404	159	249	41	124	-	691	1051	2.48
HPC(NY)	0.400	0.404	164	301	81	-	24	683	1038	2.44

Table 6 Test items

Items		Standard	Age	Note
FRESH	Slump	KS F 2402	After mixing	
	Air Content	KS F 2401	After mixing	
	Compressive Strength	KS F 2405	3,7,28,56,90 days	
	Cracking Tendency	AASHTO Designation PP. 34-99	28 days	O-Ring test
HARDENED	Freeze-Thaw Resistance (Type A Method)	KS F 2456	Every 30 cycles	300cycles
	Chloride Penetration Resistance	KS F 2711	28, 56, 90 days	RCPT
		KS F 4930	for 28 days	Ponding Test
	Scaling Resistance	ASTM C 672	50 cycles	Visual inspection

3. TEST RESULTS

3.1 Compressive Strength

Figure 1 shows the change of compressive strength according to the curing days. At early age, the compressive strength of OPC was higher than those of concrete with admixtures (HPC, HPC(NY)). It was higher 20~35% at 3 days and 7~9% at 7 days. However, the increasing rate of strength was lower in OPC than the other concrete mixtures. At 90 days, HPC had the highest compressive strength.

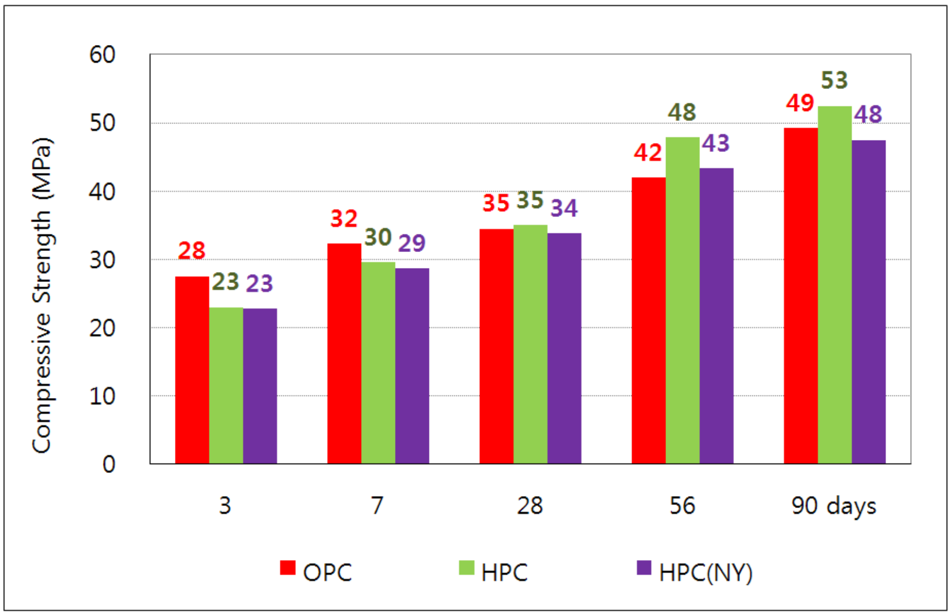


Figure 1 The change of compressive strength by ages

3.2 **Crack Resistance**

In order to evaluate the cracking characteristic caused by concrete shrinkage, an O-ring test was conducted in accordance with AASHTO Designation PP34-99. The results are shown in Picture 1.

OPC specimen showed the first crack at age 10 days, and 8 cracks (width: 0.05~0.08mm) occurred on the final 28 days. However, no crack occurred in concrete specimens with admixtures (HPC, HPC(NY)) until 28 days. This is thought that early cracking suppressed by using fly ash which is effective for the reduction of autogenous shrinkage.[6)]

(a) OPC (b) HPC, HPC(NY)

Picture 1 O-Ring test specimens at age 28 days

3.3 **Freezing-Thawing Resistance**

Figure 2 shows results of a freezing-thawing test after 300 cycles. The curing period was 56 days. HPC showed the superior performance in freezing-thawing resistance. Its relative dynamic modulus of elasticity was 80%. That of HPC(NY) was 76% and inferior to OPC.

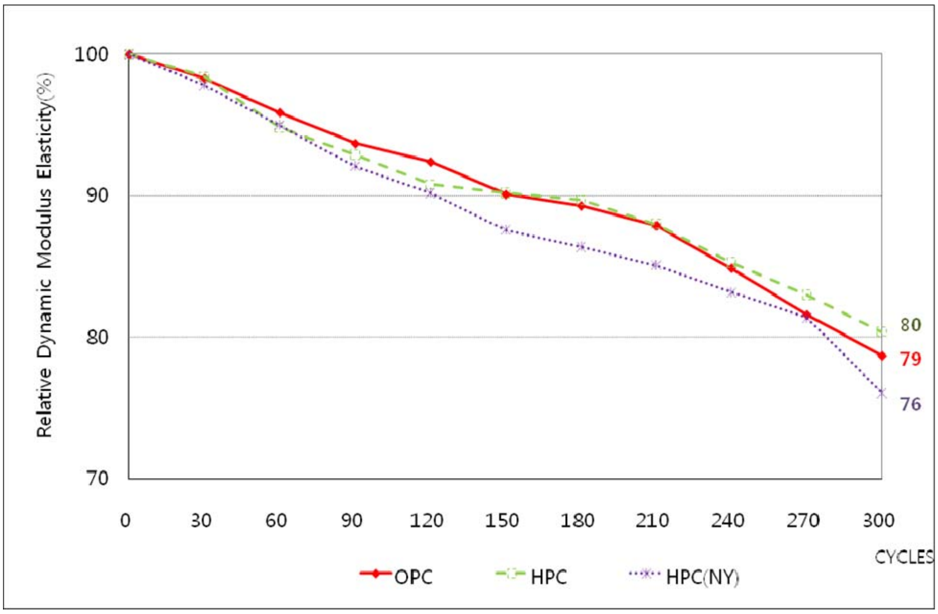


Figure 2 Test results of the freezing-thawing resistance

3.4 **Chloride Ion Penetration Resistance**

Rapid chloride permeability test was conducted by KS F 2711. As shown in Figure 3, the chloride penetration resistance gradually increased with their ages. The penetration resistances of concretes with admixtures were generally improved than OPC. At 28 curing days, the total charge passed of the concretes with ternary based binder (HPC, HPC(NY)) were less than 1000 coulombs, which were 24~38% of OPC, rated "Very Low". At 90 curing days, those of HPC, HPC(NY) were lower than 500 coulombs, which was 30~33% of OPC.

Picture 2 shows the penetration depth of chloride caused by long-term ponding test according to KS F 4930. The penetration depth of HPC was 58% of OPC and HPC(NY) was 66% of OPC.

As shown in the previous tests, the chloride ion penetration resistance of concrete was improved when admixtures were partly used as binders. HPC showed the better performance than HPC(NY) in the long-term ponding test while HPC(NY) showed the better performance than HPC in RCPT test.

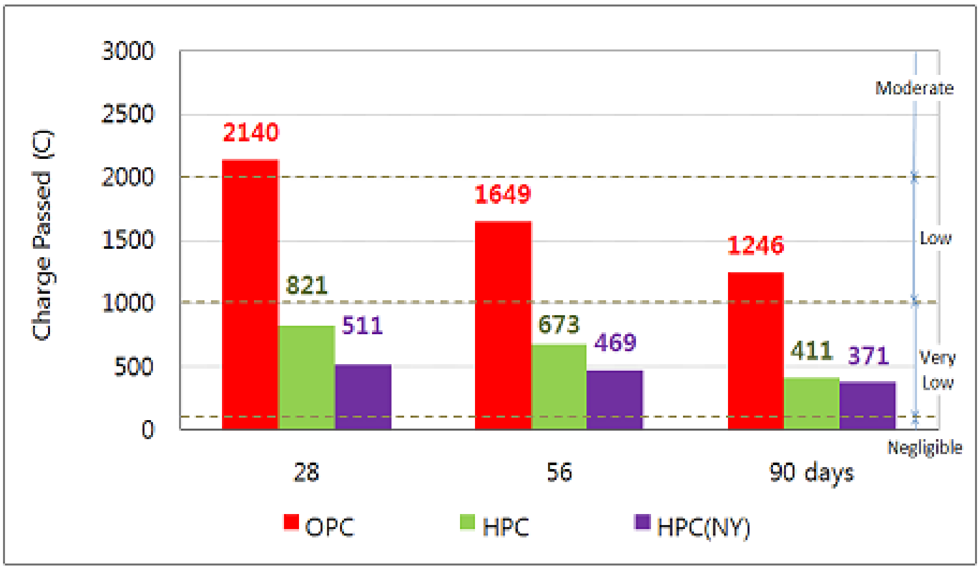


Figure 3 Rapid chloride permeability test results

(a) OPC 3.8mm (b) HPC 2.2mm (c) HPC(NY) 2.5mm

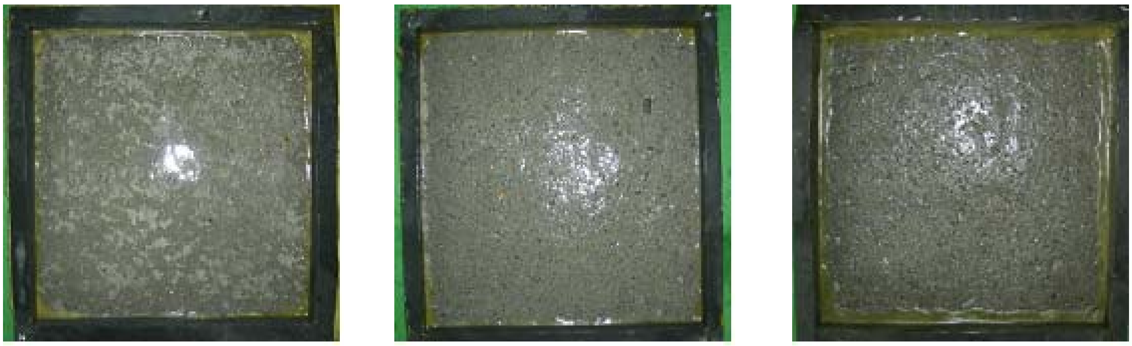
Picture 2 Long-term ponding test results

3.5 **Scaling Resistance**

Scaling resistance test was conducted by ASTM C 672 at the 56 curing days. Then, a visual inspection was performed on the top surface. After 50th cycle, light scaling on the surface of every specimen was observed. All specimens were scaling grade 1. It is hard to identify superiors in scaling resistance by visual inspection, and then weight losses of specimens were measured. It is found that HPC showed the best performance in scaling resistance and the total losses of weight were 0.176kg/m^2.

Table 7 Visual inspection results after 50 cycles

Classification	Visual Inspection results	Rating No.	Weight Losses (kg/m^2)
OPC	Laitance and a part of paste on surface was scaled and no coarse aggregate was visible	1	0.217
HPC	Laitance and a part of paste on surface was scaled and no coarse aggregate was visible	1	0.176
HPC(NY)	Laitance and a part of paste on surface was scaled and no coarse aggregate was visible	1	0.273



(a) OPC (b) HPC (c) HPC(NY)

Picture 3 Surface condition after 50 cycles

3.6 **Summary of Test Result**

The test results showed that the use of admixture could provide with the performance improvement of concrete including physical properties, durability and crack resistance. In particular, the chloride penetration resistance and water tightness were largely improved. Micro silica fume is expensive because it is not produced in South Korea, while ground granulated blast furnace slag and fly ash are not expensive because they are produced. Therefore, considering the cost and durability, HPC with both of ground granulated blast furnace slag and fly ash as admixtures was selected as the best method for improving the service life of concrete bridge deck.

4. **FIELD APPLICATION**

In order to evaluate the practical merits of the findings in this study, an experimental field application of HPC bridge deck was carried out at a bridge on Honam Expressway. Table 8 shows an overview of the test bridge.

Table 8 The status of Test Bridge

Lane Name	Super Structure	Length(m)	Width(m)	Deck Area(m^2)	Construction Co.
Honam Expressway	Preflex Girder	30.0	13.0	390	SJ Company

There was required no additional facilities or manpower because the developed ternary based cement was produced and blended by a cement manufacturer. Concrete mixing could be processed with the existing concrete batch plant. There was no problem in producing the high performance concrete of 30MPa. The HPC was placed by the pump car then the deck surface was finished by a deck-finisher as the same way of an OPC bridge deck.

At the time of concrete placement, the evaporation rate was calculated by measuring the air temperature, relative humidity, concrete temperature, and wind speed to prevent plastic shrinkage cracking as shown in Table 9. Although the air temperature on the placement day was high about 30℃, it is enough to keep the evaporation rate not exceeding 0.5kg/m^2/hr because the relative humidity was high and wind speed was low. To prevent plastic cracking, a curing agent was sprayed right after surface finishing, and then wet curing blankets were covered. The moisture curing was continuously supplied for 14 days.

According to the follow-up survey, there was no crack on the deck. As shown in table 10, the performance characteristics of the HPC at the construction field appeared better than equal to those of the HPC in laboratory.

Table 9 Evaporation rate from concrete surface according to the weather condition

Setting Time	Air Temperature (℃)	Relative Humidity (%)	Concrete Temperature (℃)	Wind Velocity (km/hr)	Evaporation Rate (kg/m^2/hr)
8:00	30.6	62.5	29.6	0.0	0.12
8:30	27.1	66.9	30.0	3.7	0.29
9:00	27.6	66.5	34.0	2.0	0.38
9:30	30.7	60.6	36.5	2.4	0.48
10:00	31.1	58.4	29.5	1.3	0.19
10:30	31.3	58.0	31.1	2.5	0.29
11:00	33.6	51.4	36.5	2.5	0.50
11:30	31.0	53.7	31.4	6.5	0.50
12:00	33.1	51.1	31.3	5.5	0.50
12:30	33.7	52.1	32.0	2.2	0.35

(a) Placing concrete

(b) Wet Curing

(c) Waterproof

(d) Follow-up survey (after 8 months)

Picture 4 Test bridge

Table 10 Test results of durability for specimens of Test Bridge

Classification		Test results (Average)	Note
Crack resistance		No Crack	until 56 days
Compressive Strength (MPa)		42.7 / 47.1 / 50.1	28 / 56 / 90 days
Freeze-thawing Resistance (type A method)		83	300 cycles
RCPT (Coulombs)		595 / 377 / 365	28 / 56 / 90 days "Very Low"
Scaling Resistance	Rate	0~1	Visual Inspection
	Weight Losses	0.1~0.2 kg/m^2	

5. CONCLUSIONS

1. The HPC - that the binder was composed of 60% cement, 30% ground granulated blast furnace slag, and 10% fly ash by weight ratio - was turned out to improve the durability of concrete bridge decks as well as crack resistance.
2. No problem was found in the experimental field application of HPC with the ternary-based cement, which was produced and blended by OEM.
3. According to the follow-up survey after 8 months from the placement of HPC bridge deck, there was no crack. And the compressive strength and durable characteristics were better than equal to the laboratory test results.

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